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1

㊿物体面とスペクトル面までの距離が大きいフーリエ変換レンズ

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㊼特許請求の範囲

1　物界側から順にみて、第1群には物界側に凸面を向けた正の単レンズ、第2群には物界側に凸面を向けたメニスカス状の負の単レンズ、第3群と第4群には物界側に凹面を向けた負の単レンズ、第5群と第6群には物界側に凹面を向けたメニスカス状の正の単レンズ、第7群には像界側に凸面を向けた正の単レンズ、第8群には物界側に凸面を向けた正の単レンズを配してなる8群8枚構成にして、

f：レンズ系全系の合成焦点距離

$f_1 \cdot f_4$：第1群から第4群までの合成焦点距離

$d_1 \cdot d_3$：第1群のレンズの物界側の面から第2群のレンズの像界側の面までの軸上距離

$d_{8 \cdot 13}$：第4群レンズの像界側の面から第7群のレンズの像界側の面までの軸上距離

d_{15}　：第8群のレンズの軸上厚み

n_p　：正の単レンズの屈折率

n_N　：負の単レンズの屈折率

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とするとき、

(1)　$-0.85f < f_{1 \cdot 4} < -0.60f$

(2)　$0.06f < d_{1 \cdot 3} < 0.20f$

(3)　$0.18f < d_{8 \cdot 13} < 0.50f$

(4)　$0.04f < d_{15} < 0.20f$

(5)　$1.75 < n_p$

(6)　$1.65 < n_N$

の各条件を満足し、物体面、すなわち前側焦点面からレンズ系の前面までの距離を0.2fより大きくし、かつレンズ系の後面からスペクトル面、すなわち後側焦点面までの距離を1fより大きくしたことを特徴とするフーリエ変換レンズ。

発明の詳細な説明

本発明は、フーリエ変換ホログラムの記録、再生用のフーリエ変換レンズ系に係り、物体面とスペクトル面までの距離を大きくなし得る如く改良したフーリエ変換レンズに関するものである。

フーリエ変換を光学的に実現するためには、第1図に示すような光学系がよく用いられている。この光学系において、第1レンズℓ_1の前側焦点面$F_{1 \cdot 1}$に置かれた透過物体をコヒーレント光で左方から照明すると、透過物体のフーリエ変換されたスペクトル像が第1レンズℓ_1の後側焦点面$F_{1 \cdot 2}$上に形成される。第2レンズℓ_2の前側焦点面$F_{2 \cdot 1}$を第1レンズℓ_1の後側焦点面$F_{1 \cdot 2}$と一致するように第2レンズℓ_2を配置すると、第1レンズℓ_1の後側焦点面$F_{1 \cdot 2}$上に形成されたスペクトル像を第2レンズℓ_2により再度フーリエ変換したスペクトル像、すなわち最初の透過物体の再生像が第2レンズℓ_2の後側焦点面$F_{2 \cdot 2}$上に形成される。

このように、最初にフーリエ変換されたスペクトル像をホログラムとして記録することが、つまりフーリエ変換ホログラムの記録であり、記録されたフーリエ変換ホログラムを第1図に示す第2レンズℓ_2の前側焦点面$F_{2 \cdot 1}$に置き、スペクトル像を再生し、透過物体の再生像を得ることが、フ

ーリエ変換ホログラムの再生である。

上述のような関係が無条件に成立するのは、レンズ系の近軸領域だけであり、フーリエ変換の作用が近軸領域という限定なしに成立するためには、レンズ系の焦点距離を f、画角を ω としたとき、理想像高として $f\sin\omega$ を用いるというバイレン（Bieren）の条件がレンズ系に必要である。

ところで、フーリエ変換ホログラムの記録時、あるいはその再生時において、物体の取扱いや記録媒体の操作を容易にするためには、物体面とレンズ系の前面、およびレンズ系の後面とスペクトル面がそれぞれ大さく離れている必要がある。

本発明は、このようなフーリエ変換レンズを提供することを目的としたもので、具体的には、左右両方向からの光束に対して収差を補正する。その際、左方向からの光束に対しては、前側焦点面に絞りを設定し、右方向からの光束に対しては、後側焦点に絞りを設定する。理想像高は $f\sin\omega$ で与えればよい。これは左右両方向の光束に対して正弦条件を満足することと同じである。

以下、本発明に係るフーリエ変換レンズの基本的構成を示した第2図によつて、本発明を詳細に説明する。

すなわち、物界側から順にみて、第1群には物界側に凸面を向けた正の単レンズL_1、第2群には物界側に凸面を向けたメニスカス状の負の単レンズL_2、第3群と第4群には物界側に凹面を向けた負の単レンズL_3，L_4、第5群と第6群には物界側に凹面を向けたメニスカス状の正の単レンズL_5とL_6、第7群には像界側に凸面を向けた正の単レンズL_7、第8群には物界側に凸面を向けた正の単レンズL_8を配してなる8群8枚構成にして、

f ：レンズ系全体の合成焦点距離

$f_{1\cdot4}$：第1群のレンズL_1から第4群のレンズL_4までの合成焦点距離

$d_{1\cdot3}$：第1群のレンズL_1の物界側の面から第2群のレンズL_2の像面側の面までの軸上距離

$d_{8\cdot13}$：第4群のレンズL_4の像界側の面から第7群のレンズL_7の像界側の面までの軸上距離

d_{15} ：第8群のレンズL_8の軸上厚み

n_p ： 正の単レンズL_1，L_5，L_6，L_7，L_8の屈折率

n_N ： 負の単レンズL_2，L_3，L_4の屈折率

とするとさ、

(1) $-0.85f<d_{1\cdot4}<-0.60f$

(2) $0.06f<d_{1\cdot3}<0.20f$

(3) $0.18f<d_{8\cdot13}<0.50f$

(4) $0.04f<d_{15}<0.20f$

(5) $1.75<n_p$

(6) $1.65<n_p$

の各条件を満足し、物体面、すなわち前側焦点面からレンズ系の物界側の面までの距離を0.2fより大きくし、かつレンズ系の後面からスペクトル面、すなわち後側焦点面までの距離を1fより大きくしたことを特徴とするフーリエ変換レンズである。

以下、本発明に係るフーリエ変換レンズが上記諸条件を必要とする技術的理由について説明する。

条件の(1)は、コマフレアーの発生の防止、右方向からの光束に対する球面収差の補正、そしてペツツバール和を適正な値に保ち、かつ像面彎曲の増大を抑えるために必要な条件である。

すなわち、$f_{1\cdot4}$が条件(1)の下限値より小さくなると、負レンズL_2，L_3，L_4のパワーが弱くなるか、それとも第1群の正の単レンズL_1のパワーが強くなる。そのため、右方向からの光束に対して、球面収差がアンダーになつてしまう。さらに、レンズ系の後側の面から後側焦点面までの距離をf_{B2}とするとき、この$f_{1\cdot4}$が条件(1)の下限値より小さくなると、f_{B2}を1fより大きく保つためには、$d_{8\cdot13}$を条件(3)の上限値以上にしなければならない。そうすると、物体面からレンズ系の前面までの距離をf_{B1}とするとき、f_{B1}は0.2fより小さくなつてしまい、本発明は達成できなくなる。

逆に、$f_{1\cdot4}$が条件(1)の上限値より大きくなると、負レンズL_2，L_3，L_4のパワーが強くなるか、それとも第1群の正レンズL_1のパワーが弱くなり、本発明のような前置絞りのレンズ系においては、光束が光軸から大きく離れた位置でレンズ系を通過することになる。さらに、$f_{1\cdot4}$が条件(1)の上限値より大きくなると、第5群から第8群までの正レンズL_5，L_6，L_7，L_8によつて構成されるレンズ系のパワーが強くなり、それぞれの曲率半径が強くなる。それらの結果、右方向からの光

束に対して最大画角近辺で大きなコマフレアーが発生してしまう。これを抑えるためには、各正レンズL_5，L_6，L_7，L_8の屈折率を大きくし、それぞれの曲率半径をゆるくしていけばよいが、そうするとペツツバール和が小さくなりすぎ、右方向からの光束に対して像面彎曲が大きくなつてしまう。

条件の(2)、条件の(3)、条件の(4)は、f_{B2}を0.2fより大きく、かつf_{B2}を1fより大きくするために必要な条件であるとともに、コマフレアーの発生の防止、球面収差の補正、ペツツバール和を適正な値に保つために必要な条件である。

すなわち、d_{1-3}，d_{8-13}およびd_{15}が、同時に条件(2)、条件(3)および条件(4)の下限値より小さくなると、f_{B1}が大きくなりすぎ、右方向からの光束の最大画角近辺の光束は、光軸から非常に遠い位置でレンズ系を通過することになる。さらに、d_{8-13}が条件(3)の下限値より小さくなると、第5群、第6群および第7群の正レンズL_5，L_6，L_7で、最大画角近辺の光束を急激に落とさなければならなくなり、第5群、第6群および第7群の正レンズL_5，L_6，L_7の曲率半径を強くしなければならなくなる結果、右方向からの光束に対して、最大画角近辺で大きなコマフレアーが発生してしまう。

逆に、d_{1-3}，d_{8-13}およびd_{15}が、同時に条件(2)、条件(3)および条件(4)の上限値より大きくなると、f_{B1}は0.2fより小さくなつてしまう。さらに、ペツツバール和を適正な値に保つためには、負レンズL_2，L_3，L_4の屈折率n_Nを大きくし、正レンズL_1，L_5，L_6，L_7，L_8の屈折率n_pを小さくしなければならないが、そうすると各負レンズL_2，L_3，L_4の曲率半径はゆるく、各正レンズL_1，L_5，L_6，L_7，L_8の曲率半径は強くなるために、右方向からの光束に対して球面収差がアンダーになつてしまう。

また、d_{1-3}とd_{15}が条件(2)と条件(4)の上限値より大きく、d_{8-13}が条件(3)の下限値より小さくなると、f_{B2}が1fより小さくなり、本発明は達成できない。

条件の(5)と条件の(6)は、コマフレアーの発生を抑えるために必要な条件であり、これら条件(5)と条件(6)を満足しない屈折率のレンズを用いても、ペツツバール和を一定に保つことはできるが、各

群のレンズの曲率半径が強くなり、コマフレアーが発生してしまうことになる。

次に、本発明に係るフーリエ変換レンズの具体的実施例を示す。

但し、r：物界側から順に数えた各レンズ面の曲率半径
d：物界側から順に数えた各レンズの軸上厚み、または軸上空気間隔
n：物界側から順に数えた各レンズの波長λにおける屈折率

とする。

第1実施例

f＝100　左方からの入射光線のF＝2.5
画角＝5°44′
右方からの入射光線のF＝10
画角＝23°04′
波長λ＝488mμ

	r	d	n
1	104.199	4.00	1.81958
2	291.311	0.10	
3	74.841	3.00	1.66726
4	62.072	9.50	
5	−57.611	3.00	1.66726
6	−482.652	5.00	
7	−64.327	4.00	1.66726
8	−742.573	4.00	
9	−133.112	9.50	1.81958
10	−79.775	0.50	
11	−233.885	8.00	1.81958
12	−111.824	0.50	
13	1744.803	9.00	1.81958
14	−102.579	0.10	
15	142.239	5.00	1.81958
16	290.092		

f_{1-4}＝−66.912　f_{B1}＝40.02　f_{B2}＝122.35

第3図aは第1実施例の左方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示し、第3図bは第1実施例の右方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示している。但し、歪曲収差は理想像高をf sin ωとしている。

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第2実施例

f＝100　左方からの入射光線のF＝2.5
画角＝5°44′
右方からの入射光線のF＝10
画角＝23°04′波長λ＝488mμ

	r	d	n
1	122.282	10.00	1.81958
2	302.862	0.50	
3	87.508	6.00	1.66726
4	70.384	9.00	
5	-69.027	6.00	1.66726
6	-554.877	5.00	
7	-74.536	6.00	1.66726
8	-1095.127	5.00	
9	-169.614	13.00	1.81958
10	-100.638	0.50	
11	-261.386	13.00	1.81958
12	-143.373	0.50	
13	-2639.627	13.00	1.81958
14	-142.984	0.50	
15	159.994	10.00	1.81958
16	-1226.705		

$f_{1.4}=-78.881$　$f_{B1}=20.48$　$f_{B2}=125.49$

第4図aは第2実施例の左方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示し、第4図bは第2実施例の右方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示している。但し、歪曲収差は理想像高をf sin ω としている。

第3実施例

f＝100　左方からの入射光線のF＝2.5
画角5°44′
右方からの入射光線のF＝10
画角＝23°04′波長λ＝488mμ

	r	d	n
1	90.438	10.00	1.82717
2	178.953	0.10	
3	65.654	8.00	1.66726
4	51.510	11.00	
5	-54.096	3.70	1.66726
6	-463.515	5.00	

8

	r	d	n
7	-56.448	5.00	1.66726
8	-429.390	4.00	
9	-124.467	4.00	1.82717
10	-75.406	0.10	
11	-200.555	4.00	1.82717
12	-105.622	0.10	
13	-1985.584	8.00	1.82717
14	-86.817	0.10	
15	151.771	17.00	1.82717
16	∞		

$f_{1.4}=-65.290$　$f_{B1}=38.06$　$f_{B2}=102.45$

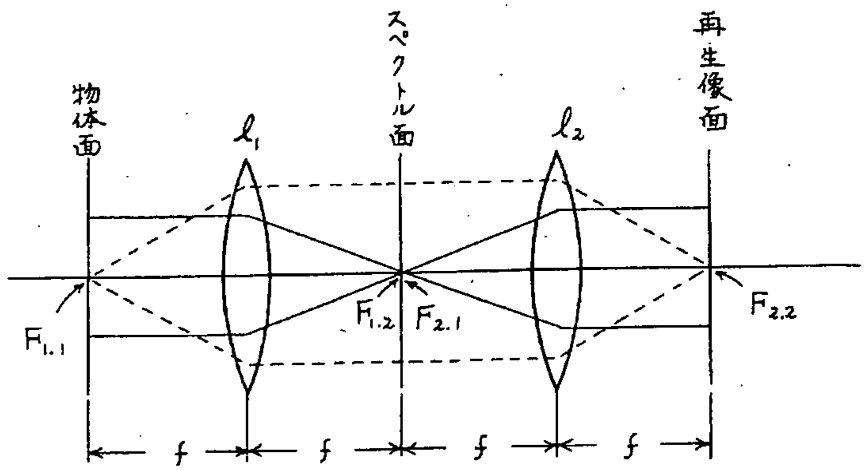
第5図aは第3実施例の左方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示し、第5図bは第3実施例の右方から入射させた光線の球面収差、正弦条件、非点収差、歪曲収差、横収差の補正状態を示している。但し、歪曲収差は理想像高をf sin ω としている。

図面の簡単な説明

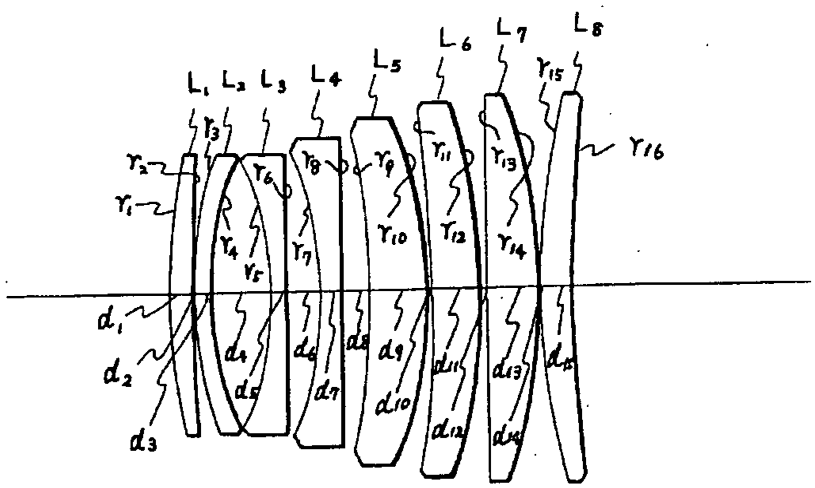
第1図はフーリエ変換用光学系の配置兼説明図、第2図は本発明に係るフーリエ変換レンズを構成するレンズ系の構成図、第3図aは第1実施例においてレンズ系に左方から入射させた光線の各収差曲線図、第3図bは第1実施例においてレンズ系に右方から入射させた光線の各収差曲線図、第4図aは第2実施例においてレンズ系に左方から入射させた光線の各収差曲線図、第4図bは第2実施例においてレンズ系に右方から入射させた光線の各収差曲線図、第5図aは第3実施例においてレンズ系に左方から入射させた光線の各収差曲線図、第5図bは第3実施例においてレンズ系に右方から入射させた光線の各収差曲線図である。

$L_1, L_2, L_3, L_4, L_5, L_6, L_7, L_8$……物界側より順次数えた構成用レンズ、$d_1, d_3, d_5, d_7, d_9, d_{11}, d_{13}, d_{15}$……物界側より順次数えた構成用レンズの軸上厚み、$d_2, d_4, d_6, d_8, d_{10}, d_{12}, d_{14}$……物界側から順次数えた構成用レンズの軸上空気間隔、$r_1, r_2, \cdots, r_{16}$……物界側から順次数えた構成用レンズの曲率半径。

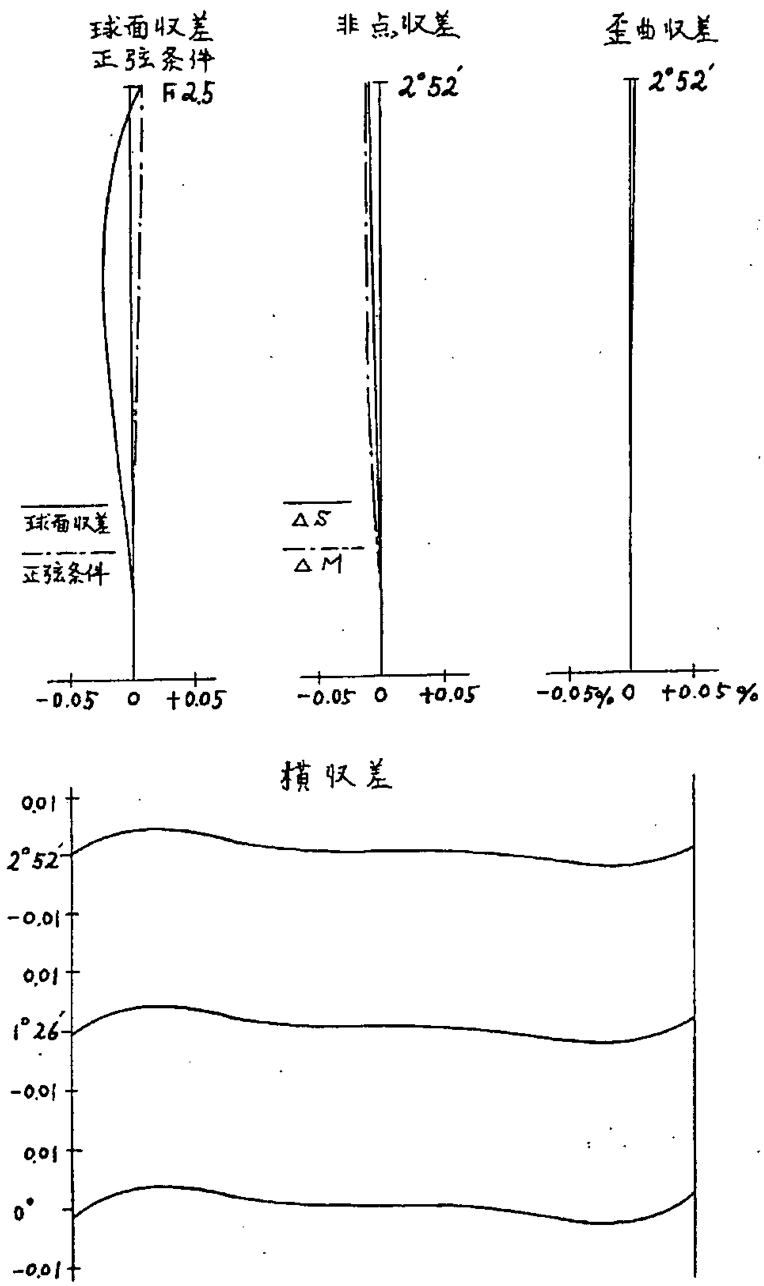
オ1図


物体面
l_1
スペクトル面
l_2
再生像面
$F_{1.1}$
$F_{1.2}$
$F_{2.1}$
$F_{2.2}$
f
f
f
f

オ2図

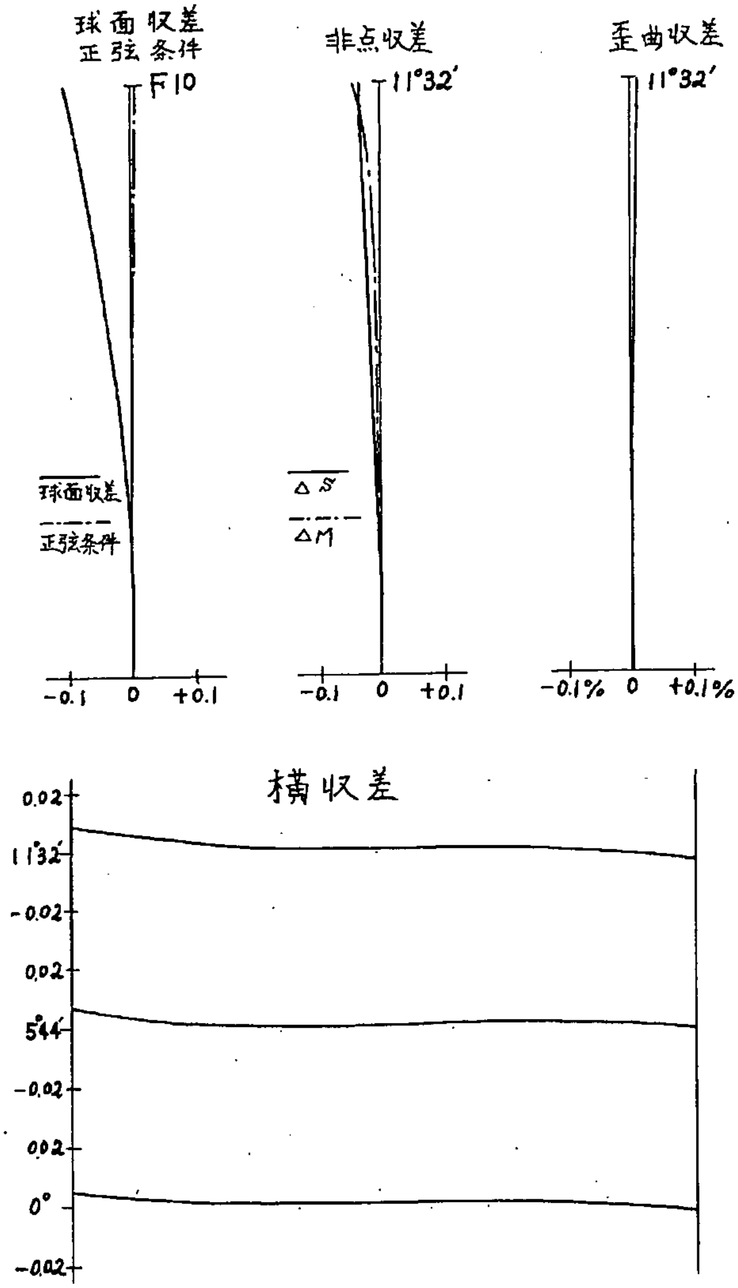

L1 L2 L3 L4 L5 L6 L7 L8
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15

才3図 (a)

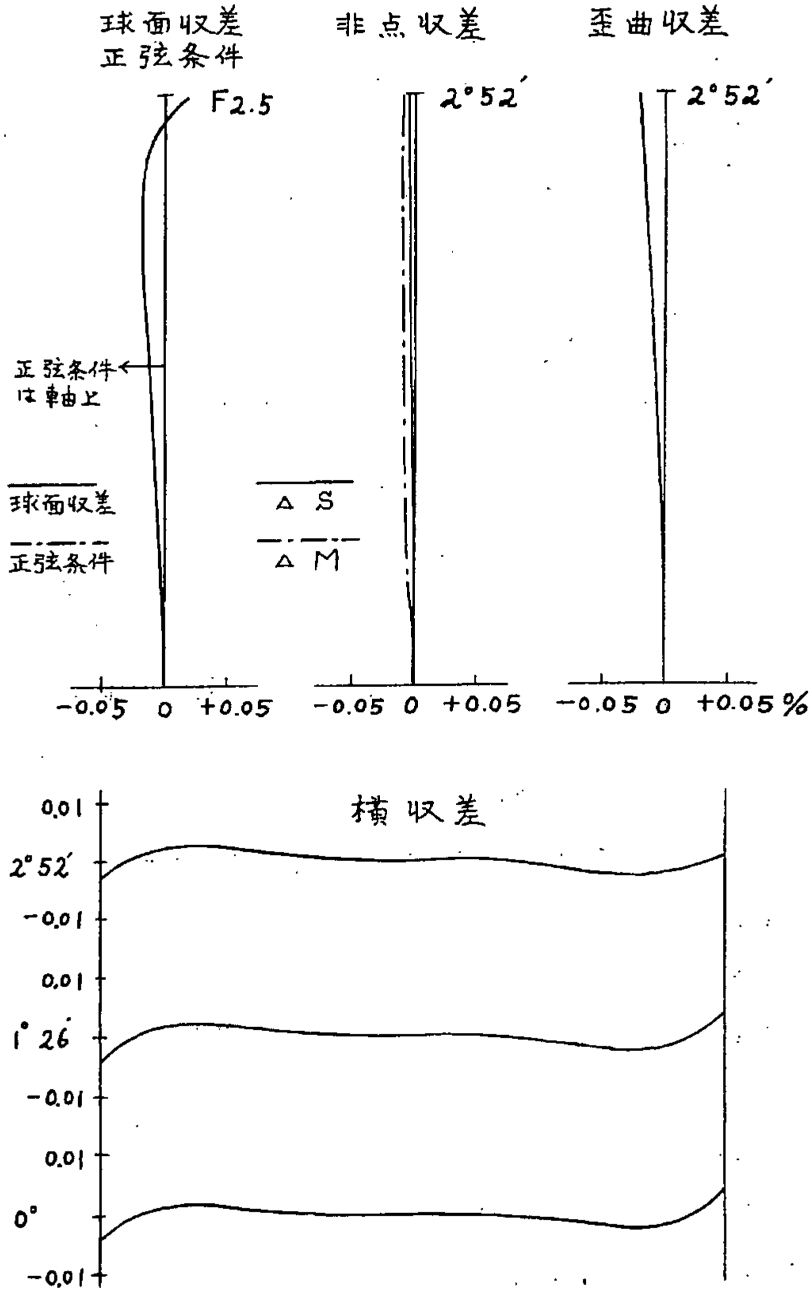


球面収差
正弦条件
F2.5
球面収差
正弦条件
-0.05
0
+0.05
非点収差
2°52′
ΔS
ΔM
-0.05
0
+0.05
歪曲収差
2°52′
-0.05%
0
+0.05%
横収差
0.01
2°52′
-0.01
0.01
1°26′
-0.01
0.01
0°
-0.01

才3図（b）


球面収差
正弦条件
F10
球面収差
正弦条件
-0.1
0
+0.1
非点収差
11°32′
ΔS
ΔM
-0.1
0
+0.1
歪曲収差
11°32′
-0.1%
0
+0.1%
横収差
0.02
11°32′
-0.02
0.02
5°44′
-0.02
0.02
0°
-0.02

第4図(a)


球面収差
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非点収差
歪曲収差
F2.5
2°52′
2°52′
正弦条件は軸上
球面収差
正弦条件
△S
△M
−0.05 0 +0.05
−0.05 0 +0.05
−0.05 0 +0.05 %
横収差
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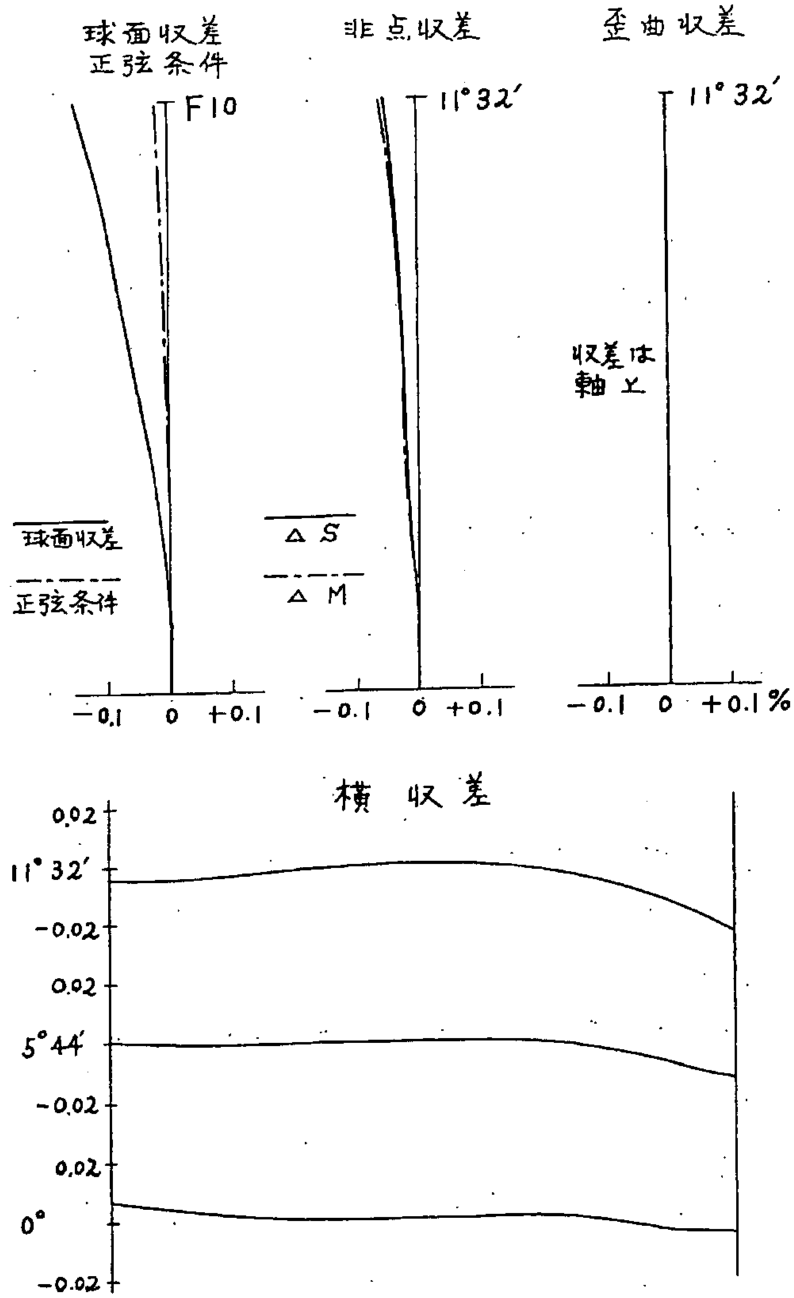
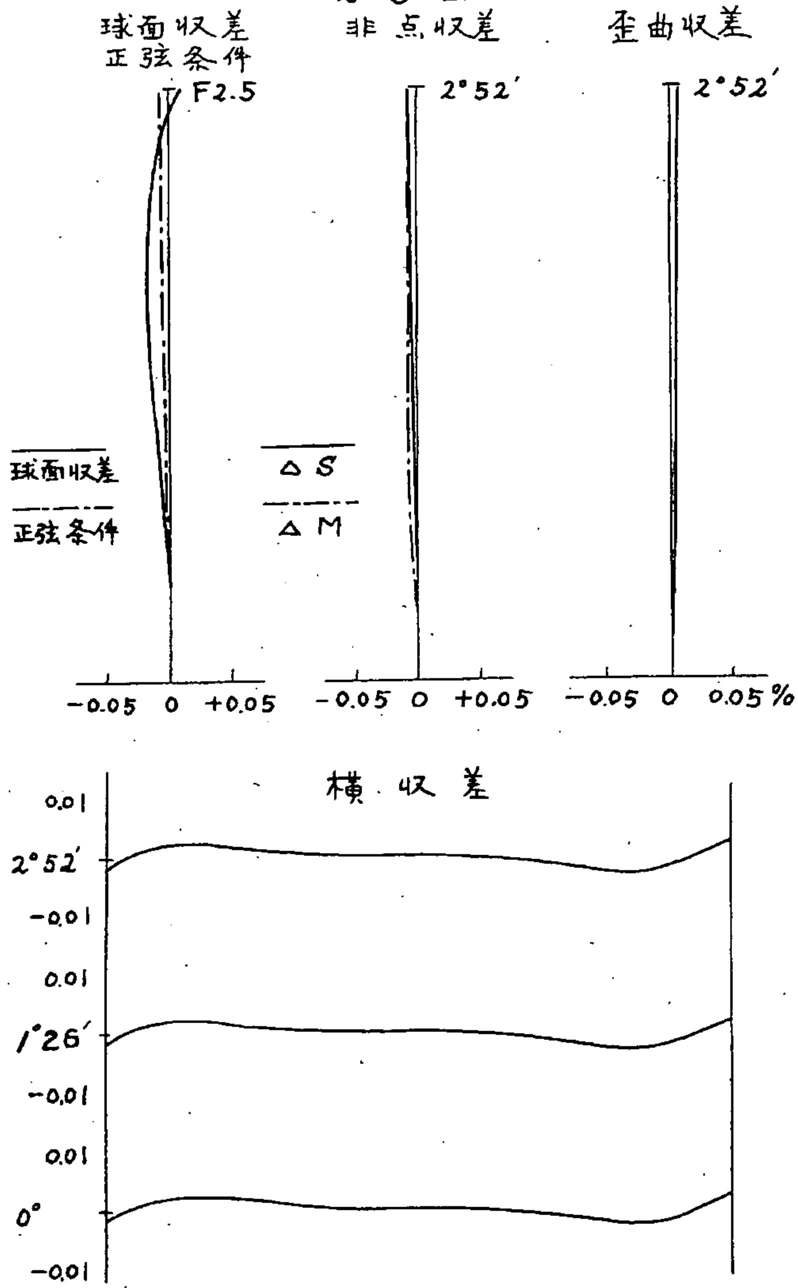
2°52′
−0.01
0.01
1°26′
−0.01
0.01
0°
−0.01

第4図 (b)


球面収差
正弦条件
F10
非点収差
11°32′
歪曲収差
11°32′
収差は
軸上
球面収差
正弦条件
ΔS
ΔM
−0.1
0
+0.1
−0.1
0
+0.1
−0.1
0
+0.1%
横収差
0.02
11°32′
−0.02
0.02
5°44′
−0.02
0.02
0°
−0.02

第5図(a)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正弦条件
F2.5
非点収差
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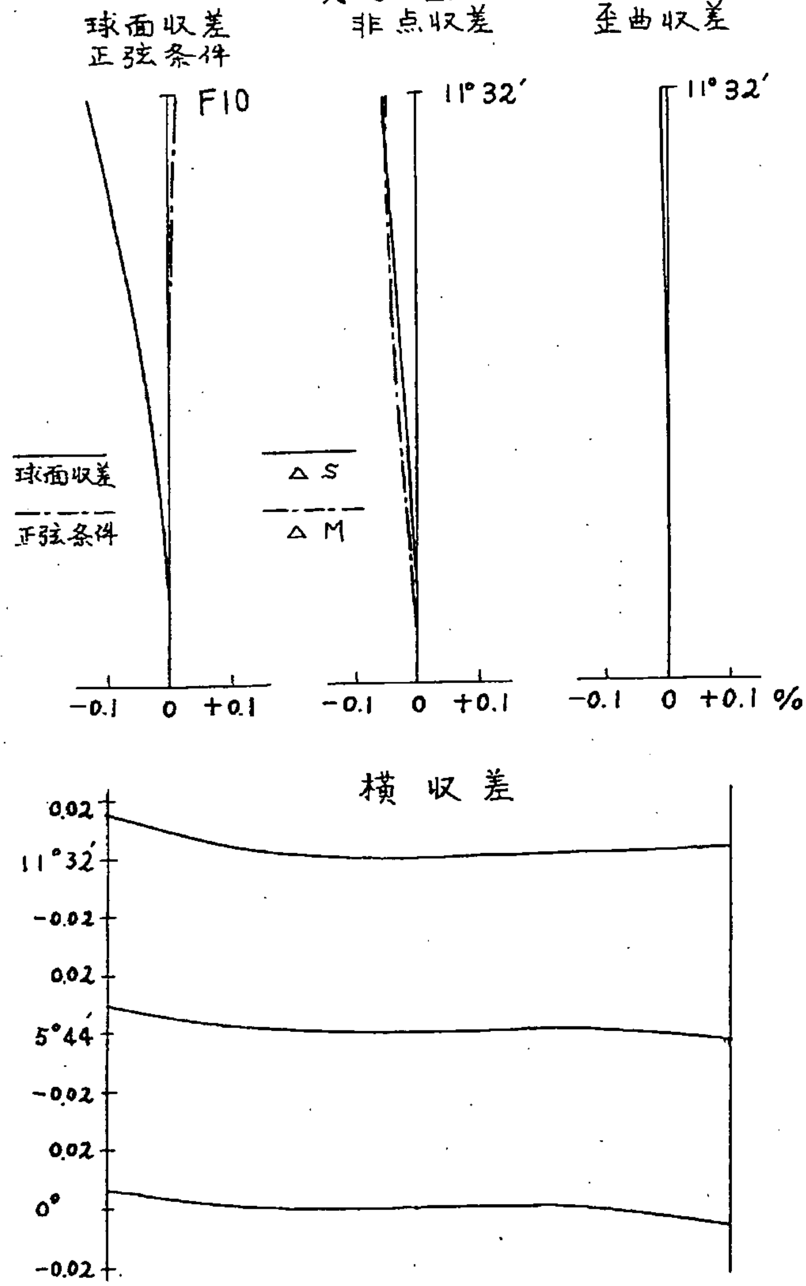
歪曲収差
2°52′
球面収差
正弦条件
ΔS
ΔM
−0.05
0
+0.05
−0.05
0
+0.05
−0.05
0
0.05%
横収差
0.01
2°52′
−0.01
0.01
1°26′
−0.01
0.01
0°
−0.01

第5図(b)


球面収差
正弦条件
非点収差
歪曲収差
F10
11°32′
11°32′
球面収差
正弦条件
ΔS
ΔM
−0.1 0 +0.1
−0.1 0 +0.1
−0.1 0 +0.1 %
横収差
0.02
11°32′
−0.02
0.02
5°44′
−0.02
0.02
0°
−0.02

Date: December 12, 2003

Declaration

I, Michihiko Matsuba, President of Fukuyama Sangyo Honyaku Center, Ltd., of 16-3, 2-chome, Nogami-cho, Fukuyama, Japan, do solemnly and sincerely declare that I understand well both the Japanese and English languages and that the attached document in English is a full and faithful translation, of the copy of Japanese Patent Publication No. Sho-56-50247 published on November 27, 1981.

M. Matsuba

Michihiko Matsuba

Fukuyama Sangyo Honyaku Center, Ltd.

FOURIER TRANSFORM LENS WITH GREAT DISTANCE BETWEEN OBJECT PLANE AND SPECTRUM PLANE

Japanese Patent Publication No. Sho-56-50247
Published on: November 27, 1981
Application No. Sho-53-89354
Filed on: July 24, 1978

Inventor: Shozo ISHIYAMA
Applicant: Konishiroku Shashin Kogyo Kabushiki Kaisha
Patent Attorney: Michio OSHIMA

SPECIFICATION

TITLE OF THE INVENTION

Fourier transform lens with great distance between object plane and spectrum plane

WHAT IS CLAIMED IS;

1. A Fourier transform lens wherein an 8-group and 8-lens structure is formed such that, in order from an object side, a first lens group has a positive single lens whose convex surface is directed to the object side, a second lens group has a meniscus-shaped negative single lens whose convex surface is directed to the object side, third and fourth lens groups each have a negative single lens whose concave surface is

directed to the object side, fifth and sixth lens groups each have a meniscus-shaped positive single lens whose concave surface is directed to the object side, a seventh lens group has a positive single lens whose convex surface is directed to an image side, and an eighth lens group has a positive single lens whose convex surface is directed to the object side, and wherein each condition of

(1) $-0.85f < f_{1\cdot4} < -0.60f$

(2) $0.06f < d_{1\cdot3} < 0.20f$

(3) $0.18f < d_{8\cdot13} < 0.50f$

(4) $0.04f < d_{15} < 0.20f$

(5) $1.75 < n_p$

(6) $1.65 < n_N$

is satisfied, and the distance from an object plane, i.e., a front focal plane to a front plane of the lens system is made greater than 0.2f, and the distance from a back plane of the lens system to a spectrum plane, i.e., a back focal plane is made greater than 1f, where

f is a combined focal length of an entire lens system,

$f_1 \cdot f_4$ is a combined focal length from the first lens group to the fourth lens group,

$d_1 \cdot d_3$ is an on-axis distance from a surface on the object side of the lens of the first lens group to a surface on the image

side of the lens of the second lens group,

$d_{8\cdot13}$ is an on-axis distance from a surface on the image side of the lens of the fourth lens group to a surface on the image side of the lens of the seventh lens group,

d_{15} is an on-axis thickness of the lens of the eighth lens group,

n_p is the refractive index of the positive single lens, and

n_N is the refractive index of the negative single lens.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a Fourier transform lens system for recording and reproducing a Fourier transform hologram, and relates to a Fourier transform lens improved so as to be capable of increasing the distance between an object plane and a spectrum plane.

An optical system shown in Fig. 1 is often used in order to optically realize a Fourier transform. In this optical system, when a transmissible object disposed at the front focal plane $F_{1.1}$ of a first lens l_1 is illuminated with coherent light from the left, a spectrum image, which has been subjected to a Fourier transform, of the transmissible object is formed on the back focal plane $F_{1.2}$ of the first lens l_1. When a second lens l_2 is disposed so that the front focal plane $F_{2.1}$ of the second lens l_2 coincides with the back focal plane $F_{1.2}$ of the first lens l_1, a spectrum image obtained by again subjecting

the spectrum image formed on the back focal plane $F_{1.2}$ of the first lens l_1 to a Fourier transform by the second lens l_2, i.e., a reproduced image of the first transmissible object is formed on the back focal plane $F_{2.2}$ of the second lens l_2.

Thus, to record the spectrum image first subjected to the Fourier transform as a hologram is, namely, to record a Fourier transform hologram, whereas to reproduce a spectrum image and obtain a reproduced image of the transmissible object while placing a recorded Fourier transform hologram at the front focal plane $F_{2.1}$ of the second lens l_2 shown in Fig. 1 is to reproduce the Fourier transform hologram.

An area where the aforementioned relationship is unconditionally established is only the paraxial area of the lens system, and, to allow the operation of the Fourier transform to be achieved without the limitation of the paraxial area, the Bieren's condition that f sin ω is used as an ideal image height is required for the lens system where f is the focal length of the lens system, and ω is a field angle.

Furthermore, in order to facilitate the handling of an object or the operation of a recording medium when a Fourier transform hologram is recorded or reproduced, a great distance is required between the object plane and the front plane of the lens system and between the back plane of the lens system and

the spectrum plane, respectively.

The present invention aims to provide the thus structured Fourier transform lens and, more specifically, to correct an aberration with respect to light beams from both right and left directions. When corrected, a stop is set at the front focal plane with respect to a light beam from the left direction, and a stop is set at the back focal plane with respect to a light beam from the right direction. The ideal image height can be given by f sin ω. This is equivalent to satisfying a sine condition with respect to the light beams of the right and left directions.

The present invention will be hereinafter described in detail with reference to Fig. 2 that shows the basic structure of the Fourier transform lens according to the present invention.

That is, the Fourier transform lens is one that is characterized in that an 8-group and 8-lens structure is formed such that, in order from an object side, a first lens group has a positive single lens L_1 whose convex surface is directed to the object side, a second lens group has a meniscus-shaped negative single lens L_2 whose convex surface is directed to the object side, third and fourth lens groups each have a negative single lens L_3, and L_4 whose concave surface is

directed to the object side, fifth and sixth lens groups each have a meniscus-shaped positive single lens L_5, and L_6 whose concave surface is directed to the object side, a seventh lens group has a positive single lens L_7 whose convex surface is directed to an image side, and an eighth lens group has a positive single lens L_8 whose convex surface is directed to the object side, and characterized in that each condition of

(1) $-0.85f < d_{1\cdot 4} < -0.60f$

(2) $0.06f < d_{1\cdot 3} < 0.20f$

(3) $0.18f < d_{8\cdot 13} < 0.50f$

(4) $0.04f < d_{15} < 0.20f$

(5) $1.75 < n_p$

(6) $1.65 < n_N$

is satisfied, and the distance from an object plane, i.e., a front focal plane to a surface on the object side of the lens system is made greater than 0.2f, and the distance from a back plane of the lens system to a spectrum plane, i.e., a back focal plane is made greater than 1f, where

f is a combined focal length of an entire lens system,

$f_{1\cdot 4}$ is a combined focal length from the lens L_1 of the first lens group to the lens L_4 of the fourth lens group,

$d_{1\cdot 3}$ is an on-axis distance from a surface on the object side of the lens L_1 of the first lens group to a surface on the image

side of the lens L_2 of the second lens group,

$d_{8\cdot 13}$ is an on-axis distance from a surface on the image side of the lens L_4 of the fourth lens group to a surface on the image side of the lens L_7 of the seventh lens group,

d_{15} is an on-axis thickness of the lens L_8 of the eighth lens group,

n_p is the refractive index of the positive single lens L_1, L_5, L_6, L_7, and L_8 and

n_N is the refractive index of the negative single lens L_2, L_3, and L_4.

A description will be hereinafter given of a technical reason why the Fourier transform lens according to the present invention requires the aforementioned conditions.

The condition (1) is one that is necessary to prevent the occurrence of a coma flare, to correct a spherical aberration with respect to a light beam from the right direction, to keep the Petzval sum at a proper value, and to restrict an increase in field curvature.

That is, if $f_{1\cdot 4}$ becomes smaller than the lower limit value of the condition (1), the power of the negative lens L_2, L_3, and L_4 becomes weaker, or the power of the positive single lens L_1 of the first lens group becomes stronger. Accordingly, the spherical aberration becomes under with respect to a light beam

from the right direction. Furthermore, if this $f_{1\cdot4}$ becomes smaller than the lower limit value of the condition (1), $d_{8\cdot13}$ must be greater than the upper limit value of the condition (3) in order to keep f_{B2} greater than 1f where f_{B2} is the distance from the back plane of the lens system to the back focal plane. If so, f_{B1} becomes smaller than 0.2f, and the present invention cannot be achieved, where f_{B1} is the distance from the object plane to the front plane of the lens system.

In contrast, if $f_{1\cdot4}$ becomes greater than the upper limit value of the condition (1), the power of the negative lens, L_2, L_3, and L_4 becomes stronger, or the power of the positive lens L_1 of the first lens group becomes weaker. Consequently, in the lens system of a front-placed stop as in the present invention, a light beam will pass through the lens system greatly apart from the optical axis. Furthermore, if $f_{1\cdot4}$ becomes greater than the upper limit value of the condition (1), the power of the lens system made up of the positive lenses L_5, L_6, L_7, and L_8 of the fifth lens group to the eighth lens group becomes stronger, and each curvature radius becomes stronger. As a result, a large coma flare is generated near the maximum field angle with respect to the light beam from the right direction. Although a possible way to restrict this is to increase the refractive index of each positive lens L_5,

L_6, L_7, and L_8 so as to loosen each curvature radius, the Petzval sum will become too small, and a field curvature will become too great with respect to the light beam from the right direction.

The condition (2), the condition (3), and the condition (4) are those that are necessary to make f_{B2} greater than 0.2f and make f_{B2} greater than 1f, and are those that are necessary to prevent the occurrence of a coma flare, to correct a spherical aberration, and to keep the Petzval sum at a proper value.

That is, if $d_{1 \cdot 3}$, $d_{8 \cdot 13}$, and d_{15} simultaneously become smaller than the lower limit values of the condition (2), the condition (3), and the condition (4), f_{B1} becomes too great, and a light beam near the maximum field angle of the light beam from the right direction will pass through the lens system far apart from the optical axis. Furthermore, if $d_{8 \cdot 13}$ becomes smaller than the lower limit value of the condition (3), the light beam near the maximum field angle must be sharply dropped by the positive lenses L_5, L_6, and L_7 of the fifth, sixth, and seventh lens groups, and the curvature radii of the positive lenses L_5, L_6, and L_7 of the fifth, sixth, and seventh lens groups must be strengthened, and, as a result, a large coma flare will be generated near the maximum field angle with respect to the light beam from the right direction.

In contrast, if $d_{1\cdot 3}$, $d_{8\cdot 13}$, and d_{15} simultaneously become greater than the upper limit values of the condition (2), the condition (3), and the condition (4), f_{B1} becomes smaller than 0.2f. Furthermore, in order to keep the Petzval sum at a proper value, the refractive index n_N of the negative lens L_2, L_3, and L_4 must be increased, and the refractive index n_p of the positive lens L_1, L_5, L_6, L_7, and L_8 must be decreased. However, if so, the curvature radius of each negative lens L_2, L_3, and L_4 is loosened, and the curvature radius of each positive lens L_1, L_5, L_6, L_7, and L_8 is strengthened, and therefore the spherical aberration becomes under with respect to the light beam from the right direction.

If $d_{1\cdot 3}$ and d_{15} become greater than the upper limit values of the condition (2) and the condition (4), and if $d_{8\cdot 13}$ becomes smaller than the lower limit value of the condition (3), f_{B2} becomes smaller than 1f, and the present invention cannot be achieved.

The condition (5) and the condition (6) are those that are necessary to prevent the occurrence of a coma flare. Although the Petzval sum can be kept constant even by using a lens of refractive index that does not satisfy these conditions (5) and (6), the curvature radius of the lens of each lens group is strengthened, and a coma flare will occur.

Next, a concrete embodiment of the Fourier transform lens according to the present invention will be shown.

Herein,

r is the curvature radius of each lens surface, in order from the object side;

d is the on-axis thickness or the on-axis air space of each lens, in order from the object side; and

n is the refractive index in wavelength λ of each lens, in order from the object side.

First embodiment

f=100

F of incident light beam from the left direction = 2.5

Field angle = 5°44′

F of incident light beam from the right direction = 10

Field angle = 23°04′

Wavelength λ= 488mμ

	r	d	n
1	104.199	4.00	1.81958
2	291.311	0.10	
3	74.841	3.00	1.66726
4	62.072	9.50	
5	-57.611	3.00	1.66726
6	-482.652	5.00	
7	-64.327	4.00	1.66726
8	-742.573	4.00	
9	-133.112	9.50	1.81958
10	-79.775	0.50	
11	-233.885	8.00	1.81958
12	-111.824	0.50	
13	1744.803	9.00	1.81958
14	-102.579	0.10	
15	142.239	5.00	1.81958
16	290.092		

$f_{3\cdot4} = -6.6912$ $f_{B1} = 40.02$ $f_{B2} = 122.35$

Fig. 3a shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light

beam incident from the left direction of the first embodiment, and Fig. 3b shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light beam incident from the right direction of the first embodiment. In the distortion aberration, the ideal image height is f sin ω.

Second embodiment

f=100

F of incident light beam from the left direction = 2.5

Field angle = 5°44′

F of incident light beam from the right direction = 10

Field angle = 23°04′

Wavelength λ= 488mμ

	r	d	n
1	122.282	10.00	1.81958
2	302.862	0.50	
3	87.508	6.00	1.66726
4	70.384	9.00	
5	-69.027	6.00	1.66726
6	-554.877	5.00	
7	-74.536	6.00	1.66726
8	-1095.127	5.00	
9	-169.614	13.00	1.81958
10	-100.638	0.50	
11	-261.386	13.00	1.81958
12	-143.373	0.50	
13	-2639.627	13.00	1.81958
14	-142.984	0.50	
15	159.994	10.00	1.81958
16	-1226.705		

$f_{1\cdot 4} = -78.881$ $f_{B1} = 20.48$ $f_{B2} = 125.49$

Fig. 4a shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light

beam incident from the left direction of the second embodiment, and Fig. 4b shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light beam incident from the right direction of the second embodiment. In the distortion aberration, the ideal image height is f sin ω.

Third embodiment

f=100

F of incident light beam from the left direction = 2.5

Field angle = 5°44′

F of incident light beam from the right direction = 10

Field angle = 23°04′

Wavelength λ= 488mμ

	r	d	n
1	90.438	10.00	1.82717
2	178.953	0.10	
3	65.654	8.00	1.66726
4	51.510	11.00	
5	-54.096	3.70	1.66726
6	-463.515	5.00	
7	-56.448	5.00	1.66726
8	-429.390	4.00	
9	-124.467	4.00	1.82717
10	-75.406	0.10	
11	-200.555	4.00	1.82717
12	-105.622	0.10	
13	-1985.584	8.00	1.82717
14	-86.817	0.10	
15	151.771	17.00	1.82717
16	∞		

$f_{1\cdot 4} = -65.290$ $f_{B1} = 38.06$ $f_{B2} = 102.45$

Fig. 5a shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light

beam incident from the left direction of the third embodiment, and Fig. 5b shows the correction state of the spherical aberration, the sine condition, the astigmatism, the distortion aberration, and the lateral aberration of a light beam incident from the right direction of the third embodiment. In the distortion aberration, the ideal image height is f sin ω.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an arrangement view and an explanatory drawing of an optical system for a Fourier transform, Fig. 2 is a schematic diagram of the lens system that forms a Fourier transform lens according to the present invention, Fig. 3a is a drawing of each aberration curve of a light beam incident on the lens system from the left direction in the first embodiment, Fig. 3b is a drawing of each aberration curve of a light beam incident on the lens system from the right direction in the first embodiment, Fig. 4a is a drawing of each aberration curve of a light beam incident on the lens system from the left direction in the second embodiment, Fig. 4b is a drawing of each aberration curve of a light beam incident on the lens system from the right direction in the second embodiment, Fig. 5a is a drawing of each aberration curve of a light beam incident on the lens system from the left direction

in the third embodiment, and Fig. 5b is a drawing of each aberration curve of a light beam incident on the lens system from the right direction in the third embodiment.

L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8--- formation lens in order from the object side; d_1, d_3, d_5, d_7, d_9, d_{11}, d_{13}, and d_{15}--- on-axis thickness of the formation lens in order from the object side; d_2, d_4, d_6, d_8, d_{10}, d_{12}, and d_{14}--- on-axis air space of the formation lens in order from the object side; r_1, r_2---, and r_{10}--- curvature radius of the formation lens in order from the object side.

Fig. 1

Object plane

Spectrum plane

Reproduced image plane

Fig. 3a

Spherical aberration

Sine condition

Spherical aberration

Sine condition

Astigmatism

Distortion aberration

Lateral aberration

Fig. 3b

Spherical aberration

Sine condition

Spherical aberration

Sine condition

Astigmatism

Distortion aberration

Lateral aberration

Fig. 4a

Spherical aberration

Sine condition

Sine condition is on the axis

Spherical aberration

Sine condition

Astigmatism

Distortion aberration

Lateral aberration

Fig. 4b

Spherical aberration

Sine condition

Spherical aberration

Sine condition

Astigmatism

Distortion aberration

Aberration is on the axis

Lateral aberration

Fig. 5a

Spherical aberration

Sine condition

Spherical aberration

Sine condition

Astigmatism

Distortion aberration

Lateral aberration

Fig. 5b

Spherical aberration

Sine condition

Spherical aberration

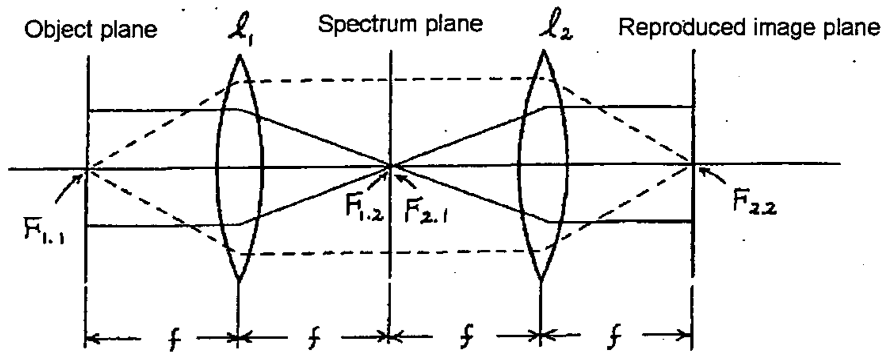
Sine condition

Astigmatism

Distortion aberration

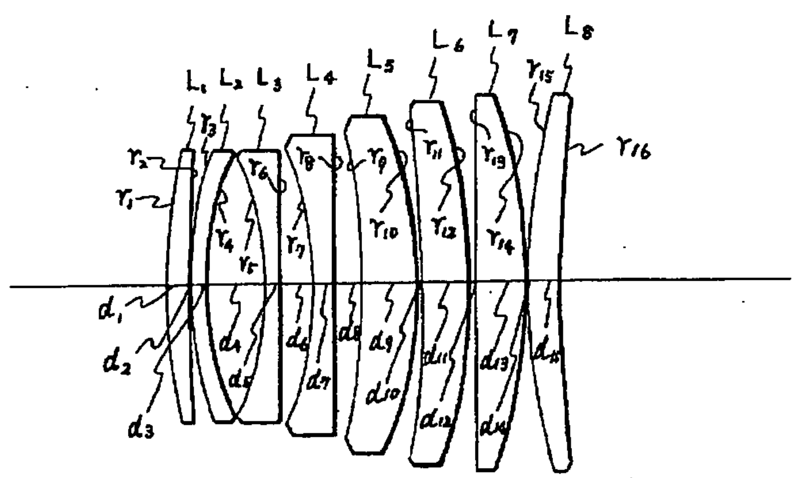
Lateral aberration

Fig. 1



Object plane
ℓ_1
Spectrum plane
ℓ_2
Reproduced image plane
$F_{1.1}$
$F_{1.2}$
$F_{2.1}$
$F_{2.2}$
f
f
f
f

Fig. 2



L1 L2 L3 L4 L5 L6 L7 L8
r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 r11 r12 r13 r14 r15 r16
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 d11 d12 d13 d14 d15

Fig. 3a

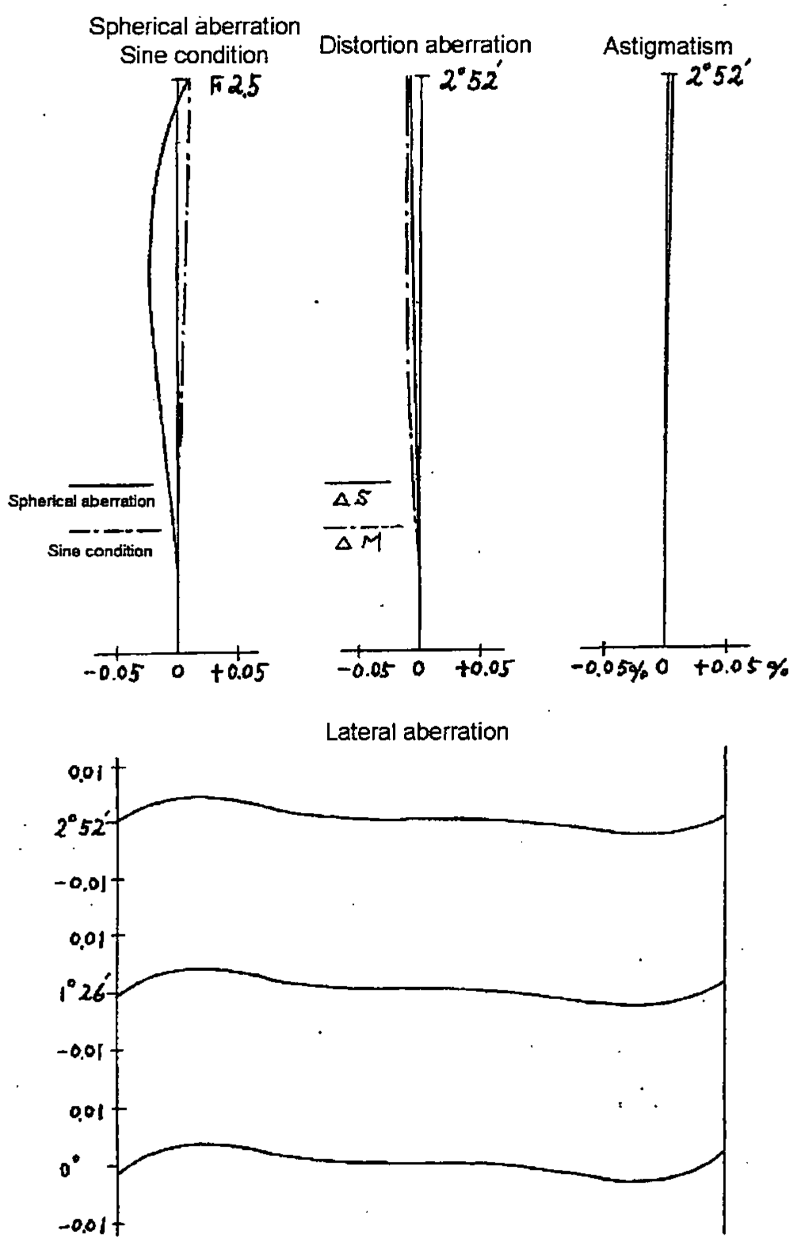
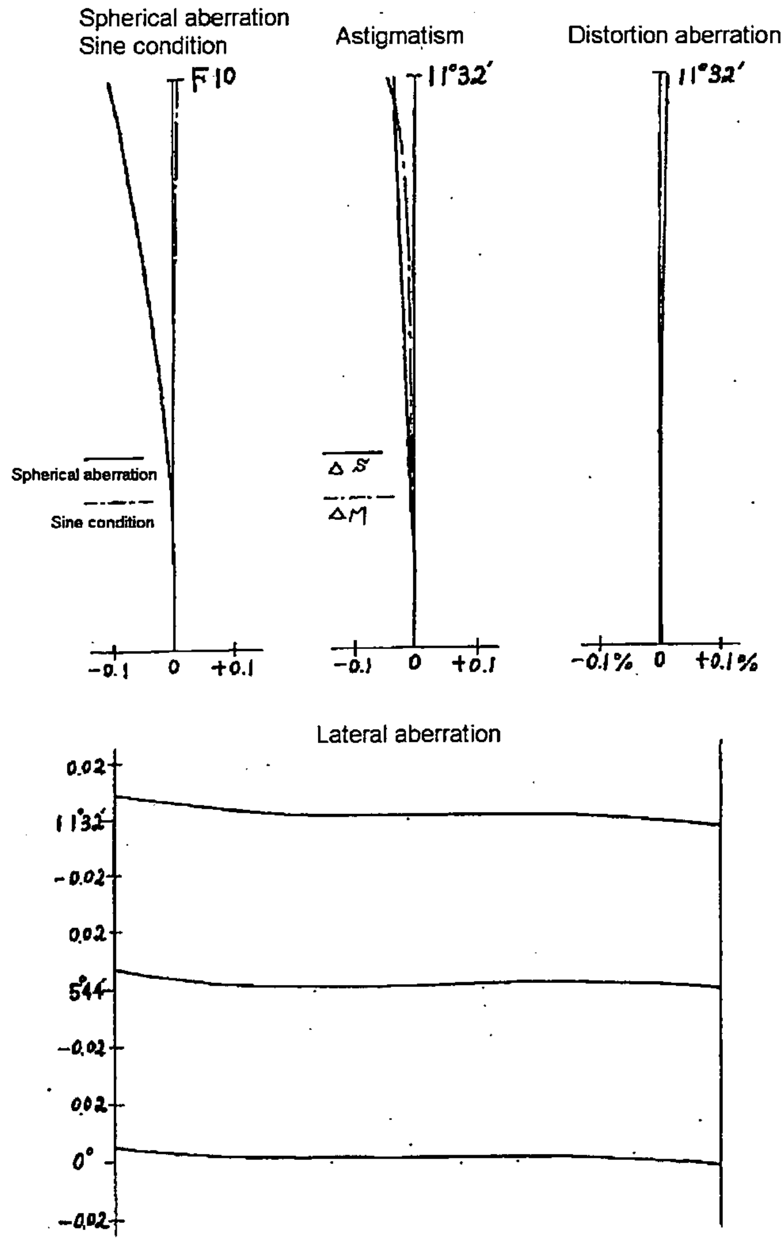
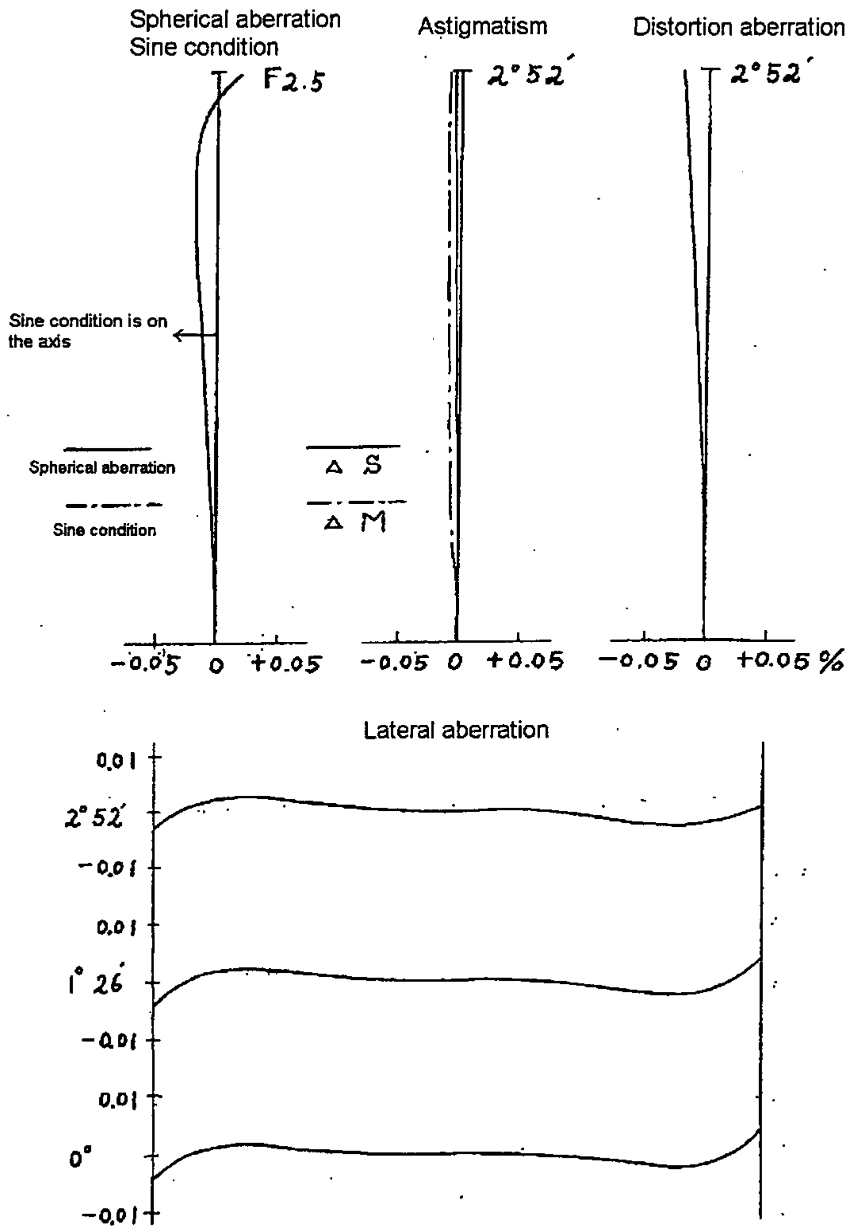

Spherical aberration
Sine condition
F2.5
Spherical aberration
Sine condition
-0.05
0
+0.05
Distortion aberration
2°52'
ΔS
ΔM
-0.05
0
+0.05
Astigmatism
2°52'
-0.05%
0
+0.05%
Lateral aberration
0.01
2°52'
-0.01
0.01
1°26'
-0.01
0.01
0°
-0.01

Fig. 3b



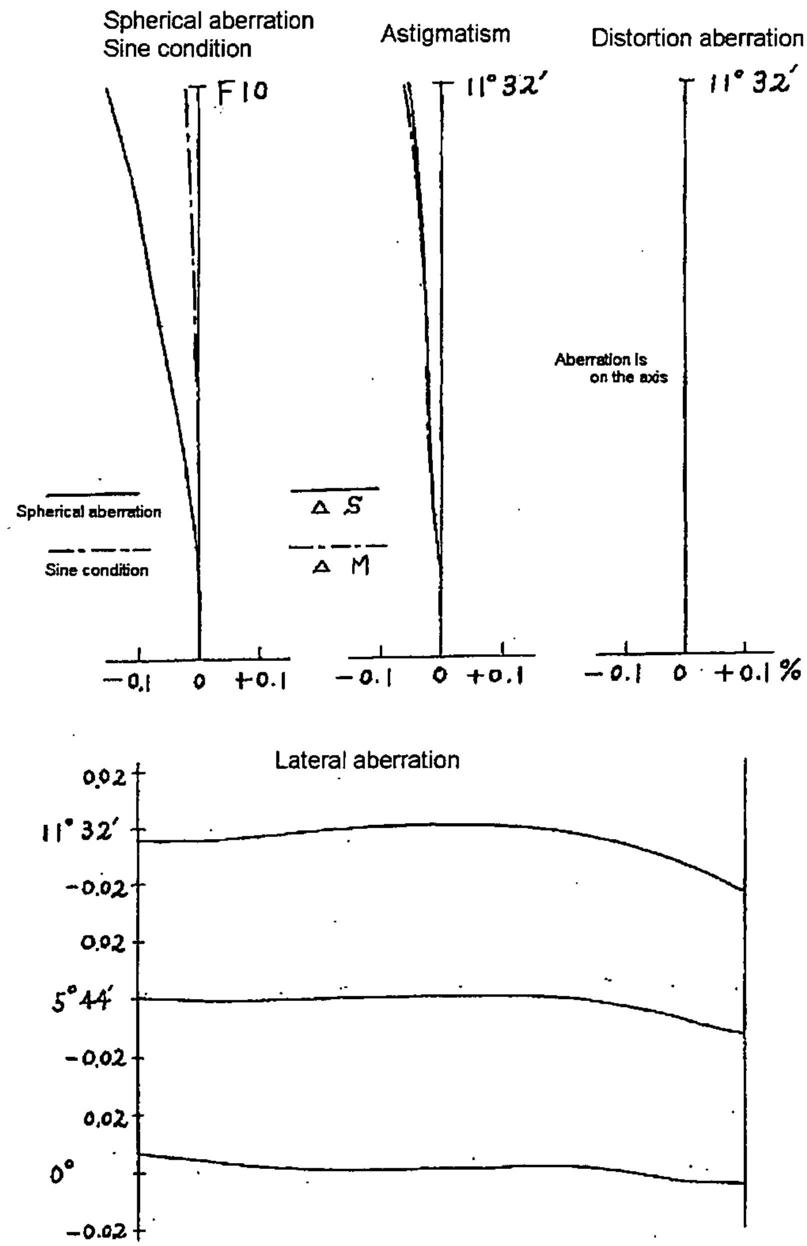
Spherical aberration
Sine condition
F10
Spherical aberration
Sine condition
-0.1
0
+0.1
Astigmatism
11°32'
ΔS
ΔM
-0.1
0
+0.1
Distortion aberration
11°32'
-0.1%
0
+0.1%
Lateral aberration
0.02
11°32'
-0.02
0.02
5°44'
-0.02
0.02
0°
-0.02

Fig. 4a



Spherical aberration
Sine condition
F2.5
Sine condition is on the axis
Spherical aberration
Sine condition
-0.05
0
+0.05
Astigmatism
2°52'
ΔS
ΔM
-0.05
0
+0.05
Distortion aberration
2°52'
-0.05
0
+0.05 %
Lateral aberration
0.01
2°52'
-0.01
0.01
1°26'
-0.01
0.01
0°
-0.01

Fig. 4b



Spherical aberration
Sine condition
F10
Spherical aberration
Sine condition
−0.1
0
+0.1
Astigmatism
11° 32′
ΔS
ΔM
−0.1
0
+0.1
Distortion aberration
11° 32′
Aberration is on the axis
−0.1
0
+0.1 %
Lateral aberration
0.02
11° 32′
−0.02
0.02
5° 44′
−0.02
0.02
0°
−0.02

Fig. 5a

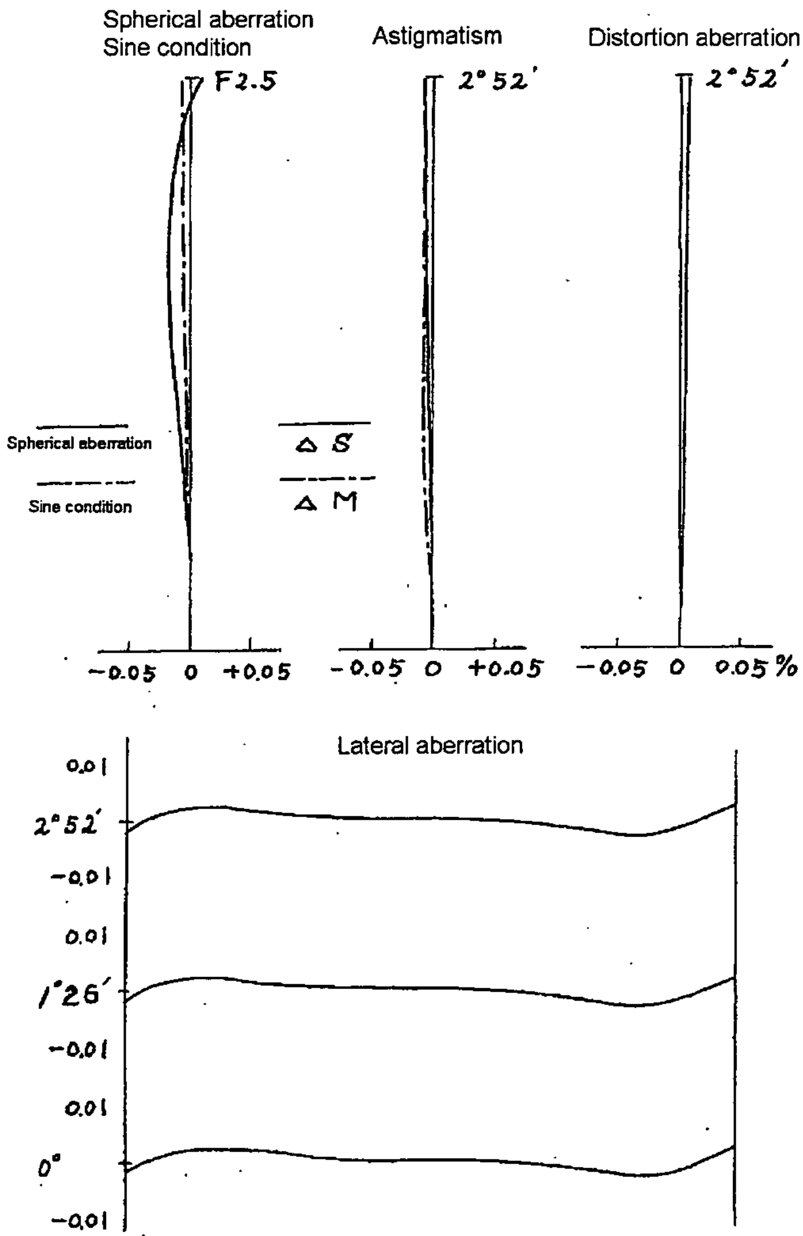
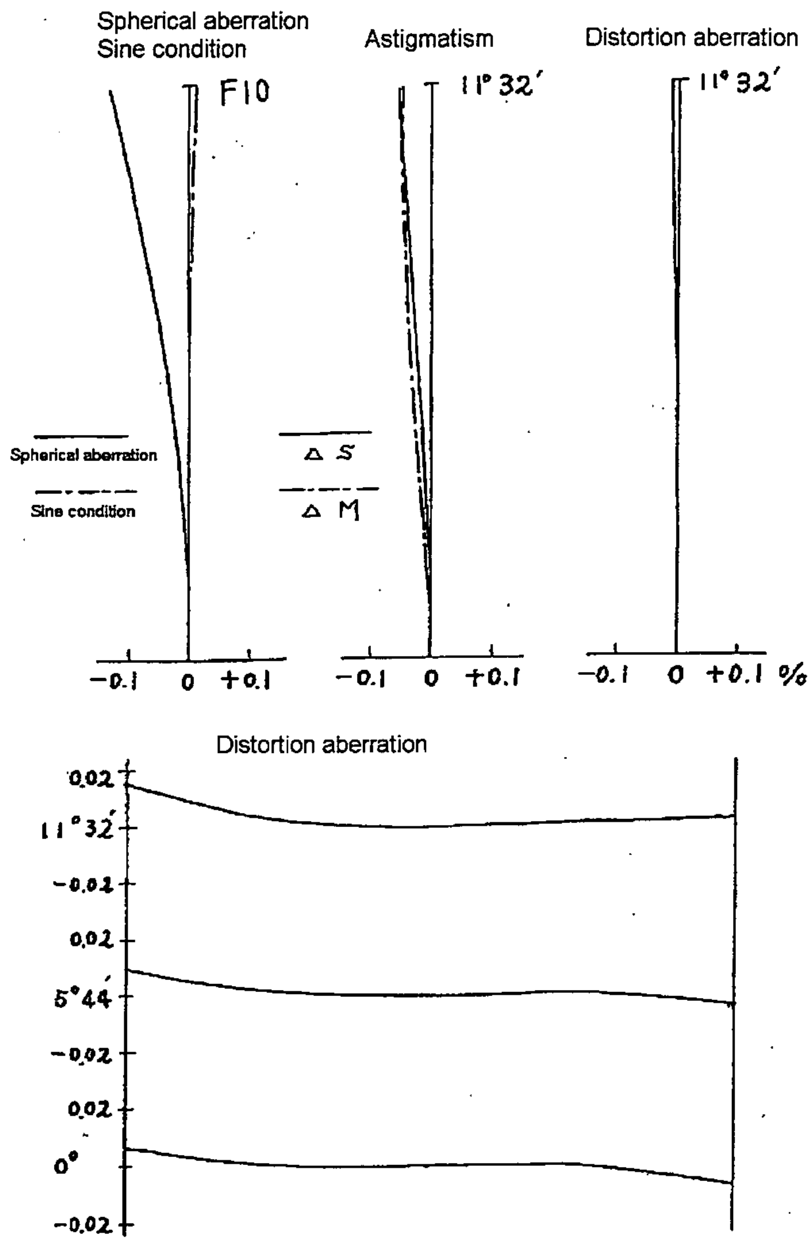

Spherical aberration
Sine condition
F2.5
Spherical aberration
Sine condition
-0.05
0
+0.05
Astigmatism
2°52'
ΔS
ΔM
-0.05
0
+0.05
Distortion aberration
2°52'
-0.05
0
0.05 %
Lateral aberration
0.01
2°52'
-0.01
0.01
1°26'
-0.01
0.01
0°
-0.01

Fig. 5b



Spherical aberration
Sine condition
Astigmatism
Distortion aberration
F10
11°32′
11°32′
Spherical aberration
Sine condition
ΔS
ΔM
-0.1
0
+0.1
-0.1
0
+0.1
-0.1
0
+0.1 %
Distortion aberration
0.02
11°32′
-0.02
0.02
5°44′
-0.02
0.02
0°
-0.02